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Simulation of Phase Contrast Imaging for Mesoscale NDE

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Happy World Toilet Day!

WORLD TOILET ORGANIZATION

It's Everybody's Business

Press Release

It's Everybody's Business!

19 November is World Toilet Day. Be our Toilet Ambassador.

On this day World Toilet Organisation wants all toilet users to get involved. Be a Toilet Ambassador. Here are 10 things that everybody can do:

1. Wipe clean the toilet seat before to ensure hygiene, and after use as a courtesy for the next toilet user
2. If the toilet is not clean or well-maintained, tell the toilet owner
3. Similarly if the toilet is well kept and maintained, praise the toilet owner for his efforts. Do more, tell it to everyone!
4. Use half-flushes to save water, and don't forget to flush too
5. Give way to the old and disabled, and help them if possible
6. Give suggestions to the toilet owner on how to make the toilet more cheerful and user-friendly
7. Treat the public toilet you are in, as if its your own at home
8. Do not be seated for too long, as the next person using waiting outside was just as anxious as you were before
9. Keep the floor dry by wiping hands or using the hand dryer after washing
10. Tell the next person about World Toilet Day, and why its so important to carry out the nine things above

Get each and everyone to add on to the 10 things mentioned above. If everyone joins in, there will be more and better public toilets.

Gators, Go!

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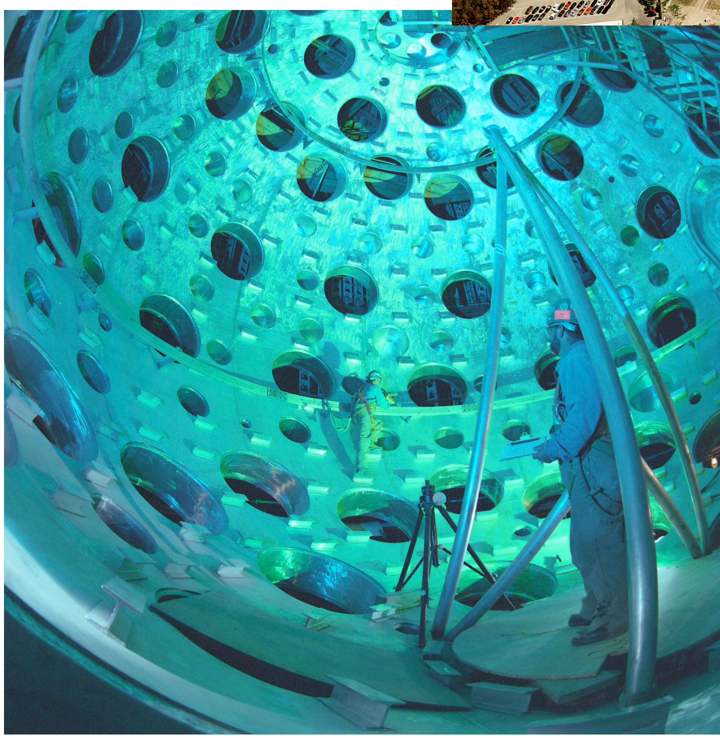
Collaborators

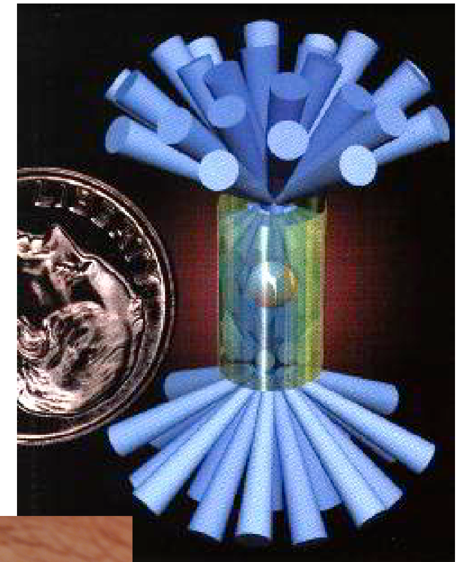
- Harry Martz, NDE on mesoscale objects
- Anton Barty, X-ray phase effects
- Dan Schneberk, Radiography and CT
- Henry Chapman, X-Ray phase effects
- Bernie Kozioziemski, NIF targets, X-Ray phase effects
- Alexis Schach von Wittenau, Radiography

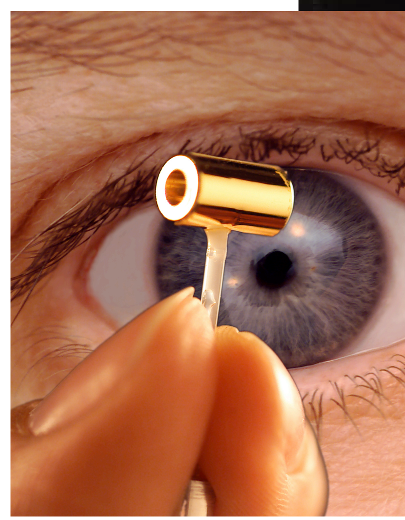
Plan for Talk

- Why LLNL cares about mesoscale targets: the National Ignition Facility (NIF)
- Phase effects in X-Ray radiography
- HADES – our radiographic simulation tool
- Some preliminary results
- Future work

National Ignition Facility Focuses 192 Laser Beams (1.8 MJ of Energy) into a Small Region

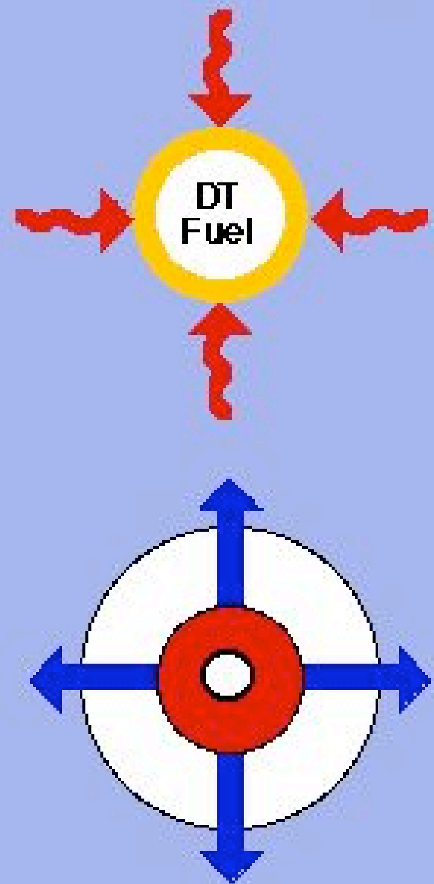






Inertial Confinement Fusion Concept

Our ultimate goal is to create a short lived, microminiature star which will release energy by thermonuclear fusion in the same manner that our sun and the stars produce energy.



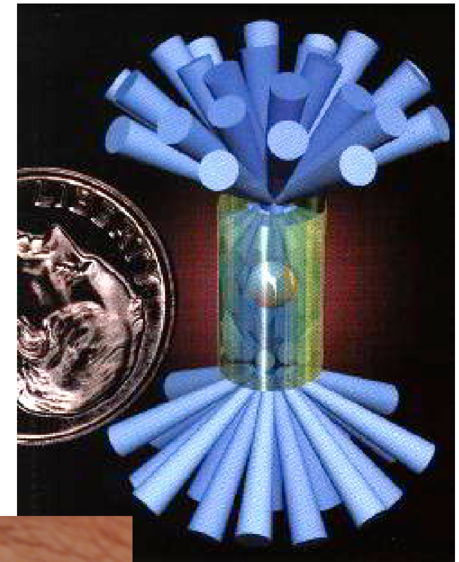
GENERAL ATOMICS

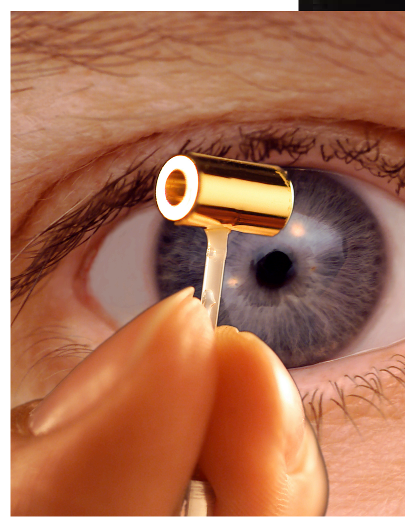
What are “Mesoscale” objects?

- Field of view of several mm

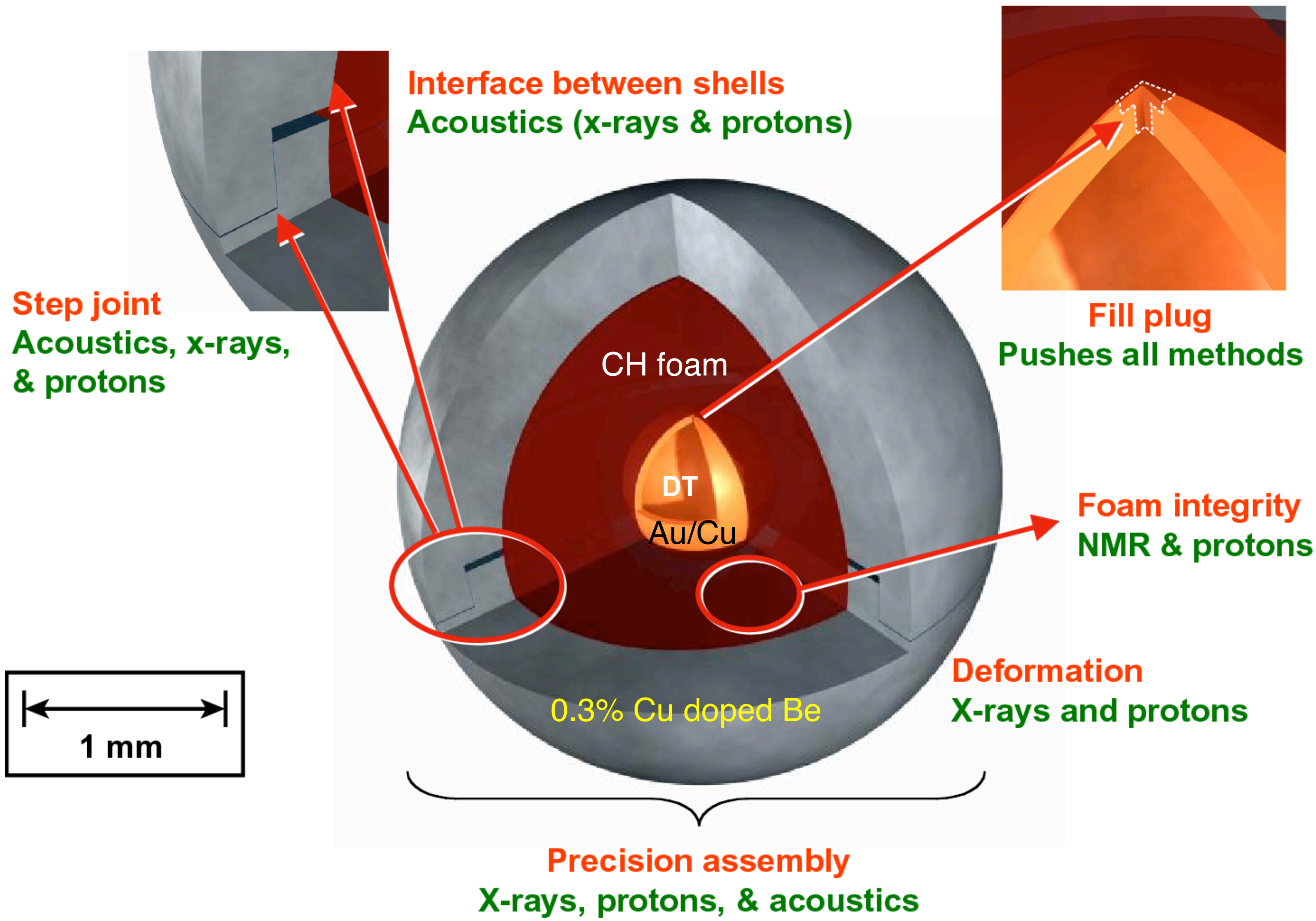
- Trying to distinguish features which are several μm in size.

- NIF targets, stylus points, …





NIF targets pose many challenges for NDE



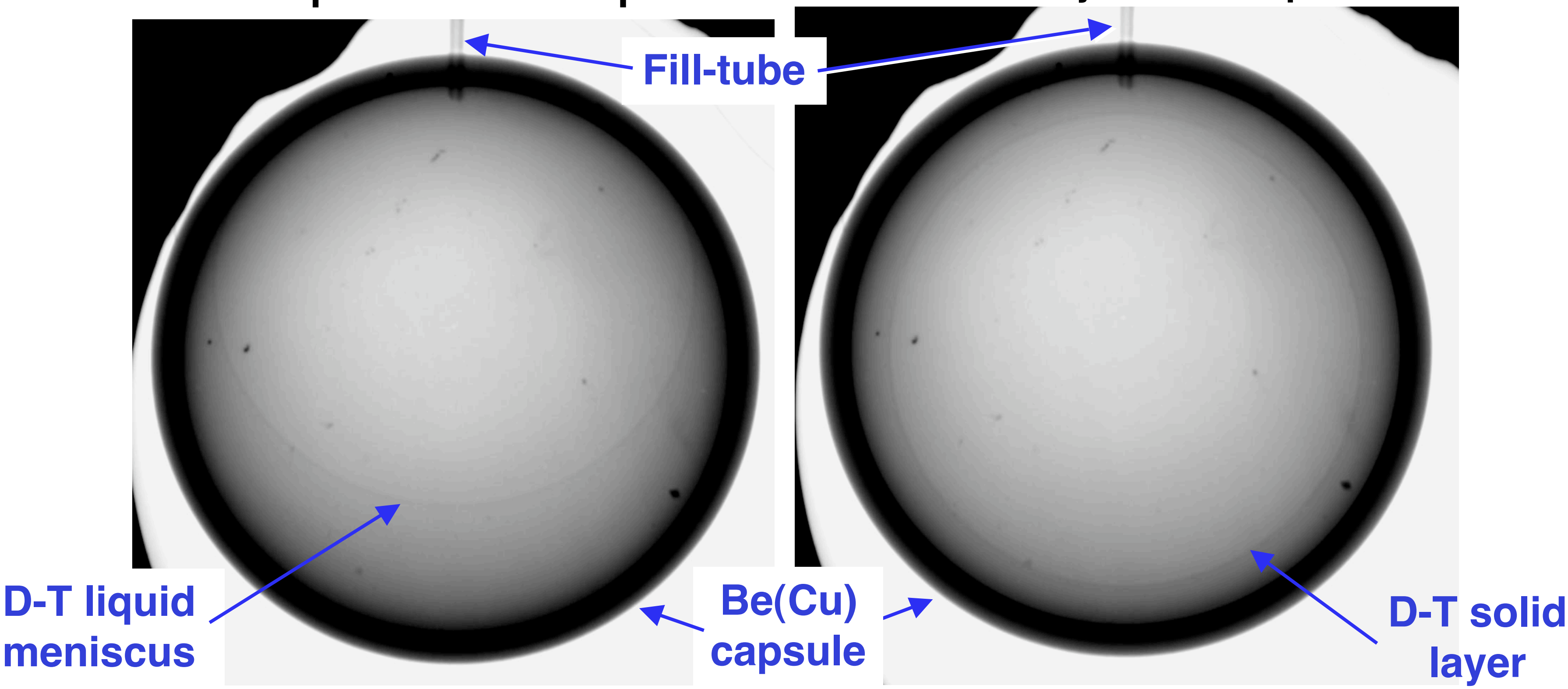
Fabricating these targets is an R&D area

- Material uniformity of exotic foams needed
- Coating properties not well known
- Metallurgy of some materials poorly known
- Micro machining to produce smooth interfaces is challenging
- Assembly is nontrivial
- How to fill small capsules with DT gas/ice at high pressures is not a solved problem

These challenges require that the as-built configurations of these parts be measured before experiments to provide initial conditions for calculations.

D-T liquid/solid layer inside of Be(Cu) shell

D-T liquid fill in Be capsule | **D-T solid layer in Be capsule**



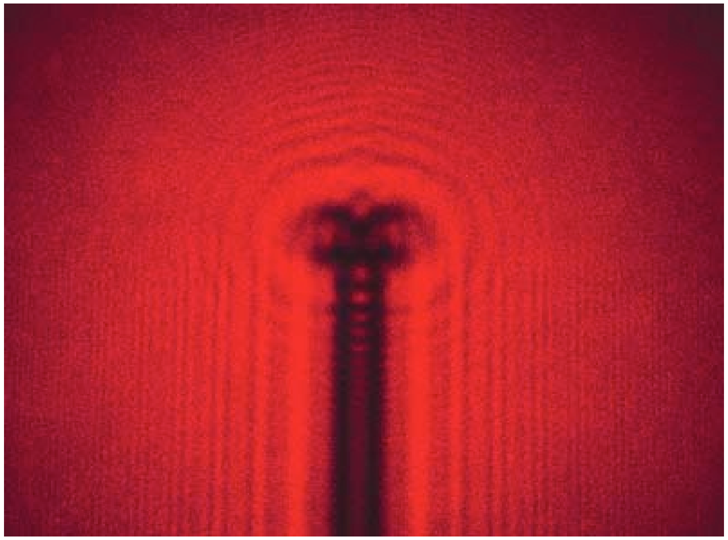
The D-T layers are only visible because of x-ray phase effects

X-ray Phase Effects

- We are using micro focus or synchrotron sources: wave properties of X-rays are not washed out.

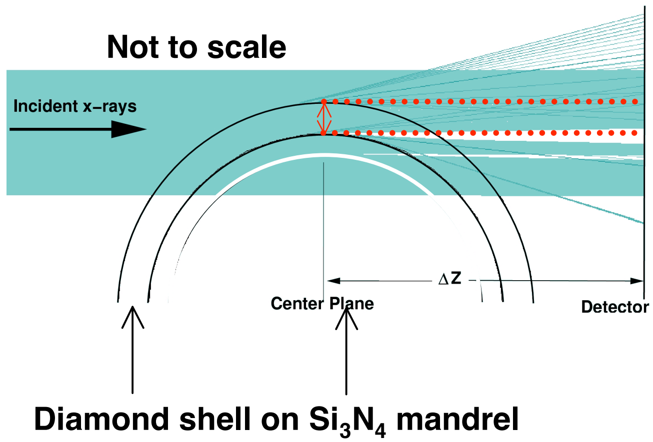
- Detectors capture diffractive *and* absorptive effects downstream.

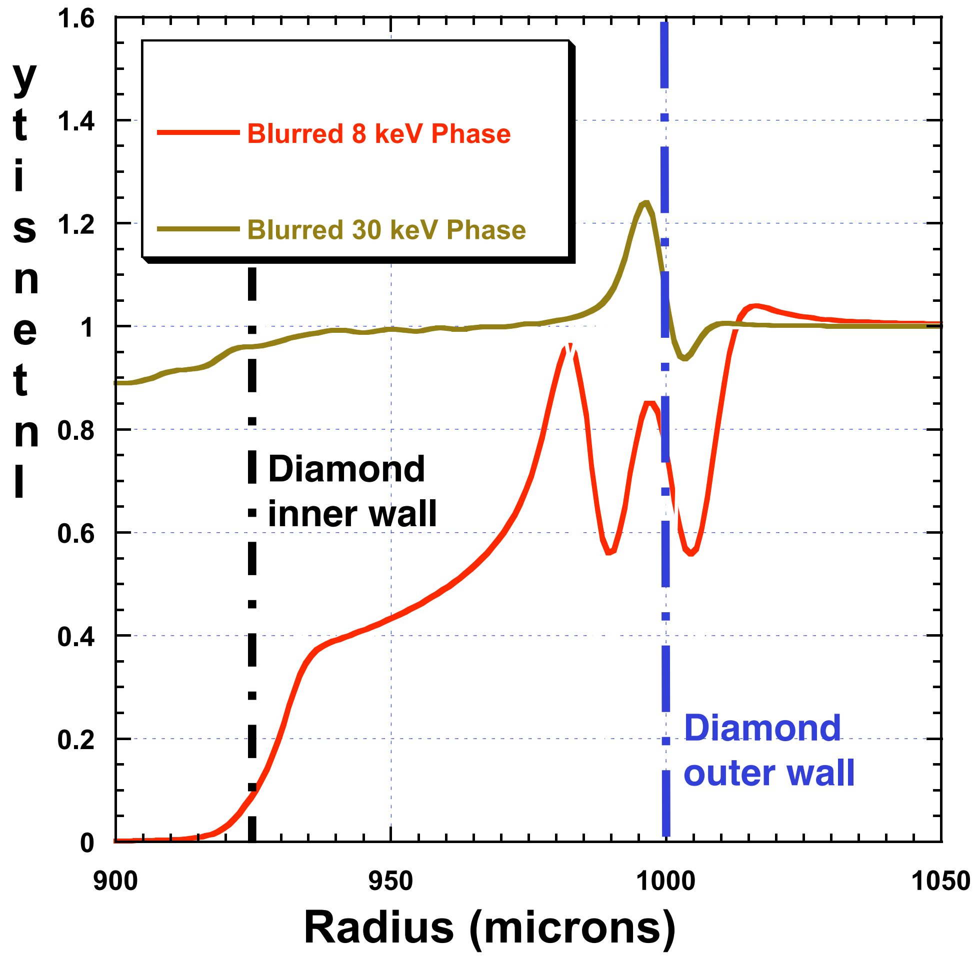
- Related to optical diffraction, except the X-Rays can penetrate the object.



Optical Image of Laser Light Diffracted by a Pin Head

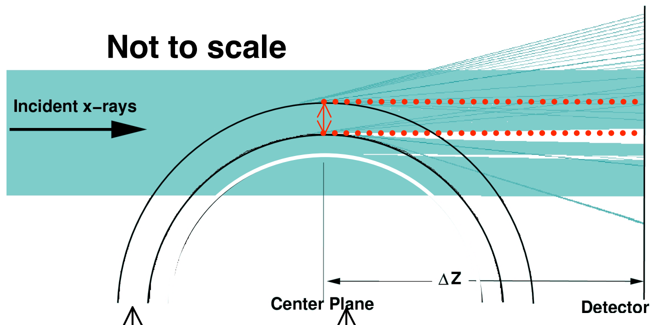
X-ray phase effects are needed for accurate image analysis results



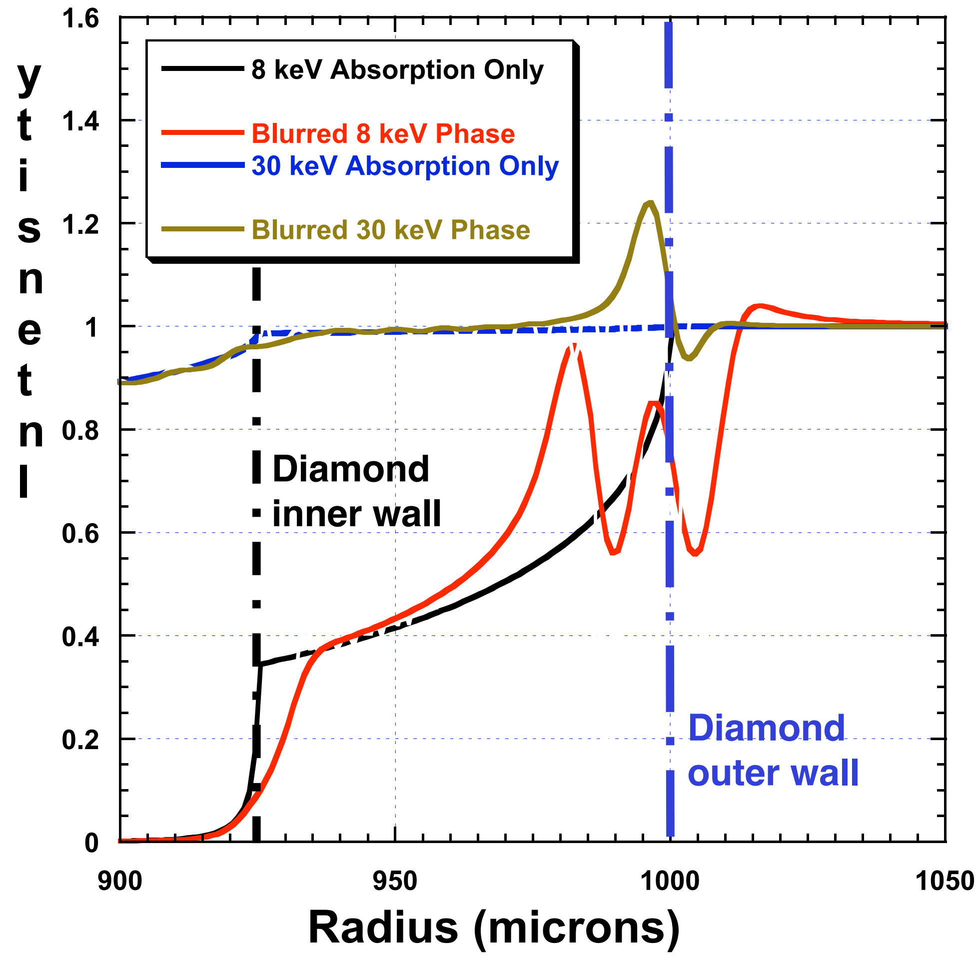


Phase effects impact both radiographic and tomographic x-ray imaging

X-ray phase effects are counterintuitive when compared with absorption imaging



Diamond shell on Si_3N_4 mandrel



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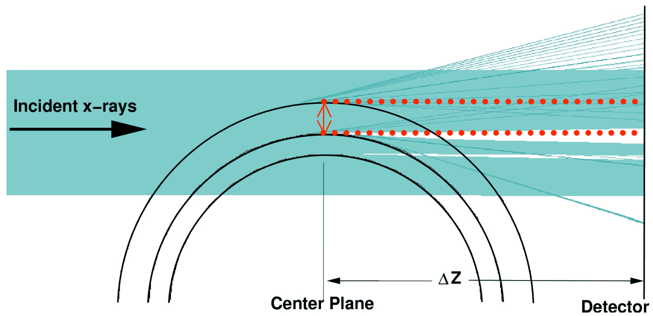
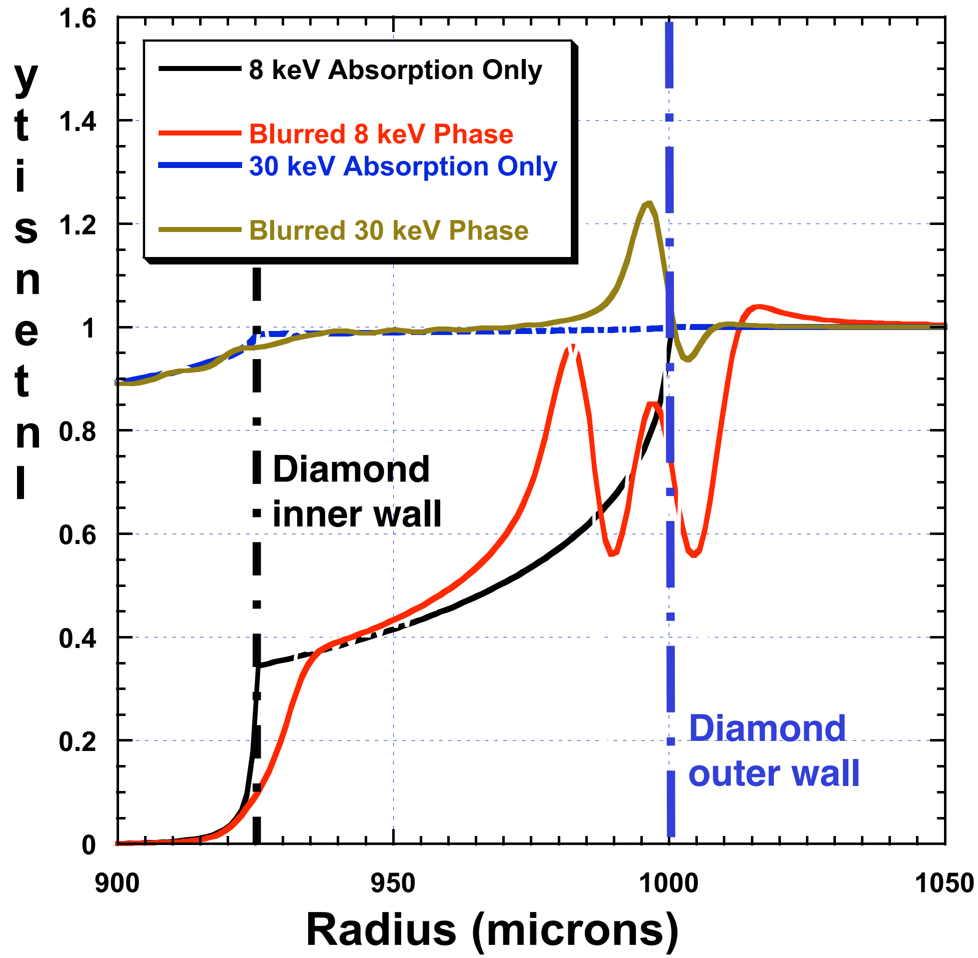


Phase effects change with
- Object materials & geometry
- Source-object-detector geometry
- Source energy
- Spatial resolution

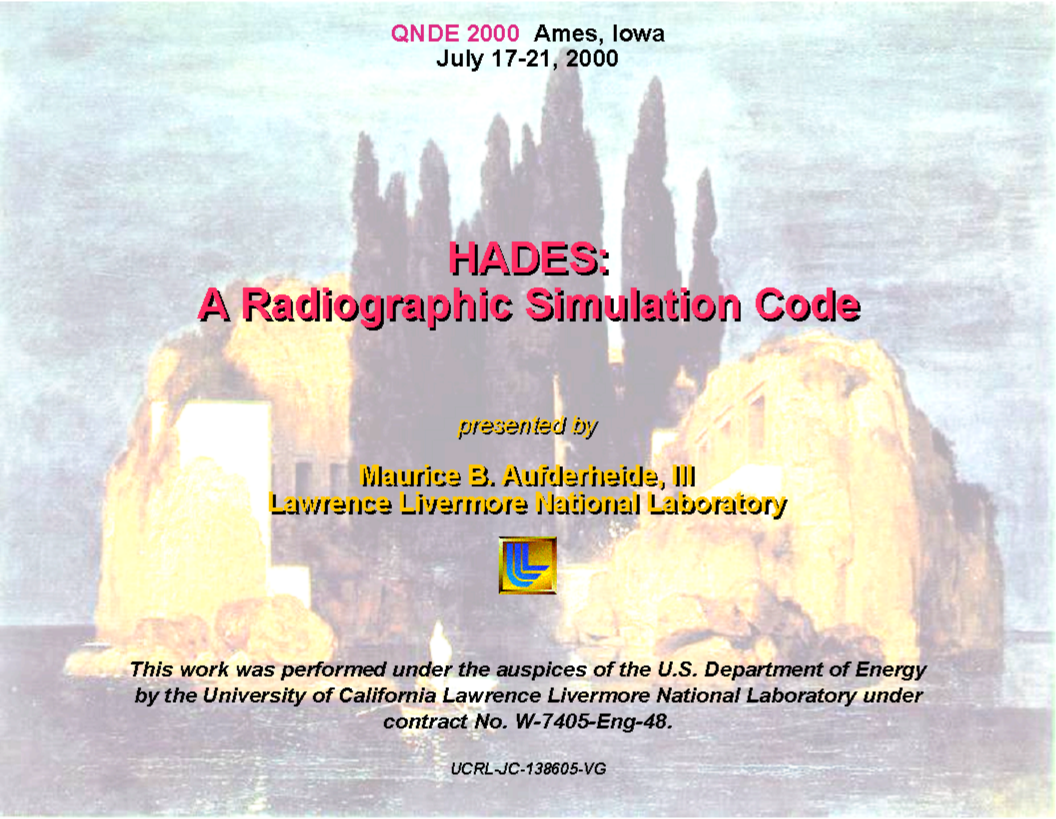
Phase effects can generate
- Dimensional errors
- Fictitious gaps
- Wrong material identification



Phase effects impact both radiographic and tomographic x-ray imaging

For These Studies I Used HADES

- HADES is a code we have developed for simulation of radiography used in industrial NDE settings.



- We reported on HADES at QNDE 2000: Aufderheide et al., *Review of Progress in QNDE,* Vol. **20A**, ed. By D.O. Thompson and D.E.Chimenti, 2001 AIP, pp. 507-513.

For These Studies I Used HADES

- HADES is a ray tracing code.

- The code simulates radiographs through finite element or finite difference mesh models of objects. Meshes which can be treated included regular and irregular cylindrical r-z meshes, 3D Cartesian meshes, and 3D generalized hexahedral meshes.

- Solid-body objects such as plates, cylinders, cones, spheres and other more complex shapes also can be included in the problem; in fact, many of our studies use no mesh models at all. The user can build even more complex objects using unions, intersections, and differences of groups of these objects.

- HADES can simulate X-Ray Radiography in the 1 keV to 100 MeV energy range, Neutron Radiography in the thermal to 30 MeV energy range, and protons in the ~500 MeV to 100 GeV energy range.

- HADES can treat spectral and monochromatic X-Ray and Neutron sources.

HADES: Continued

- HADES can include detector models in simulations, or give simpler radiographs of path length through objects.
- Finite size source spots can be simulated either by brute force calculation, or by convolution at the detector plane.
- The user can include scattering profiles in the simulation, but HADES does not simulate scattering.
- We can use POVRay to render the radiographic geometry.
- HADES can do some calculations in parallel, for computationally intense simulations.
- HADES has been ported to SGI and Compac workstations, Crays, and ASCI Blue Pacific.

Our goal has been to simulate radiography with as high a fidelity as possible, with a fast turn-around time.

Why “HADES”?

In Greek Mythology, ‘□□□□□ is the the underworld, the land of the dead.

In old-fashioned English translations of these legends, the dead in ‘□□□□□ are referred to as “shades” or shadows:

“This is the last word that Ajax speaks to you. The rest he will tell to the shades in Hades.”

Sophocles <u>Ajax</u> 864-865

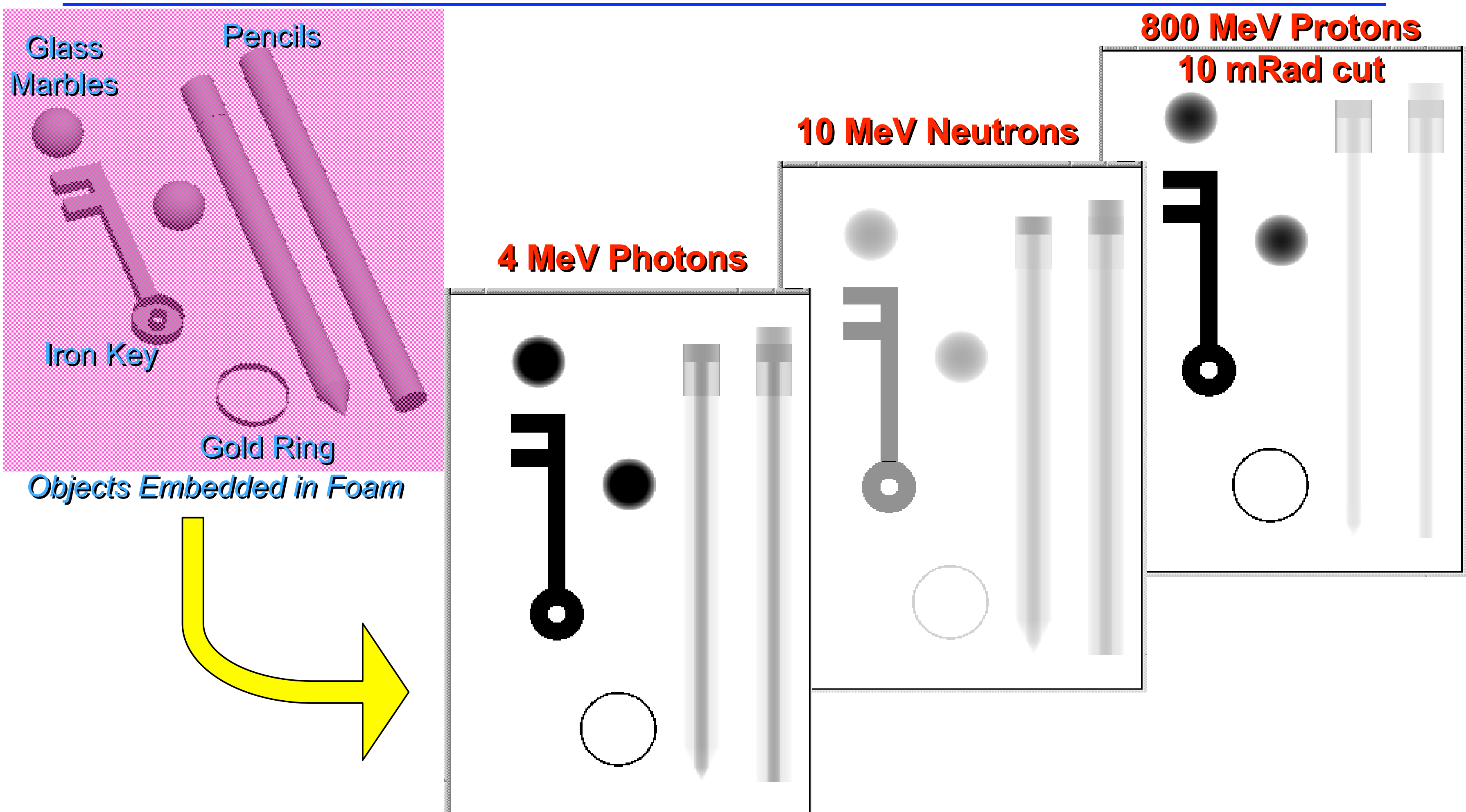
Radiography is the study of objects by observing their shadows. Hence the name.

The Isle of the Dead

Arnold Böcklin

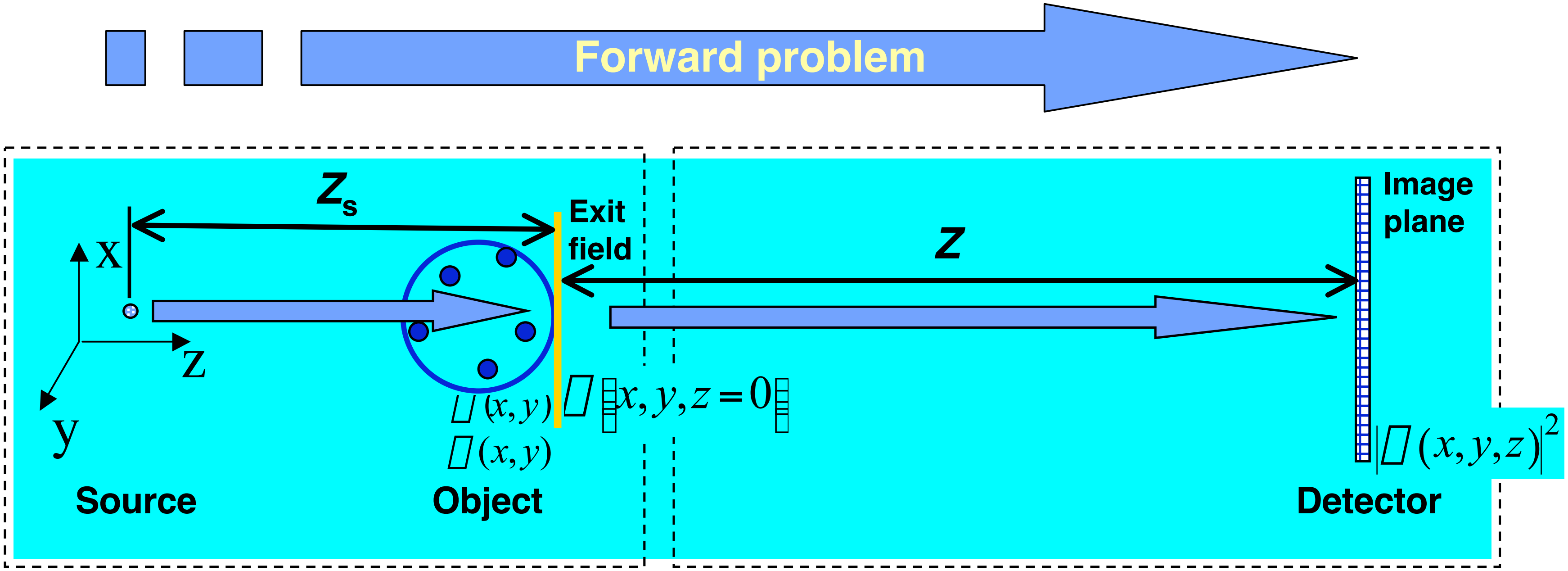
1880

Simulated Radiographs Using Gammas, Neutrons, Protons



HADES allows easy comparison between various probes. We are now extending HADES to include X-Ray phase effects

Modeling phase effects with HADES



HADES computes □ and □ via ray tracing

- The index of refraction, *n*, is 1- □ – i □.

$$\square = \frac{r_e \square^2}{2\square} \square N_A \square_i \frac{X_i}{A_i} f_{1,i}$$

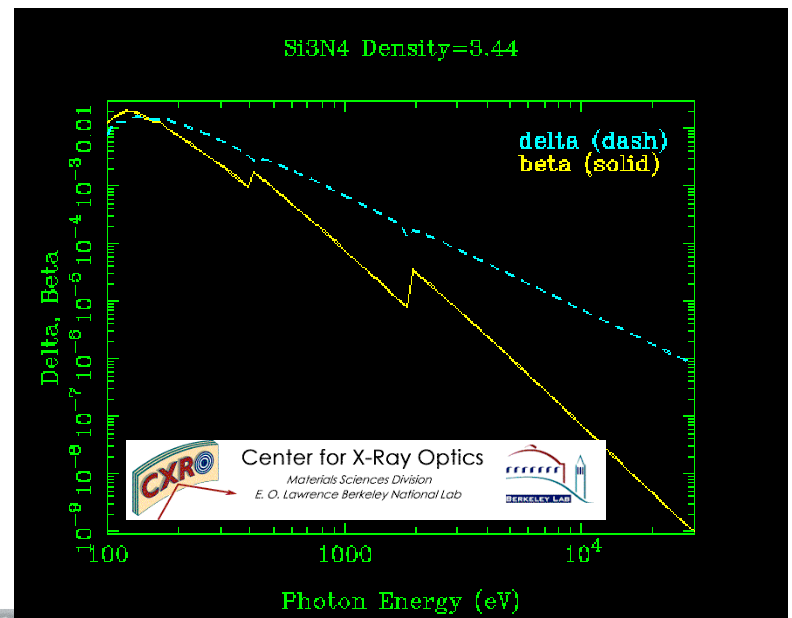
$$\square = \frac{r_e \square^2}{2\square} \square N_A \square_i \frac{X_i}{A_i} f_{2,i}$$

- We use the CXRO tables for f_1 and f_2.
- HADES computes □ and □ using these quantities:

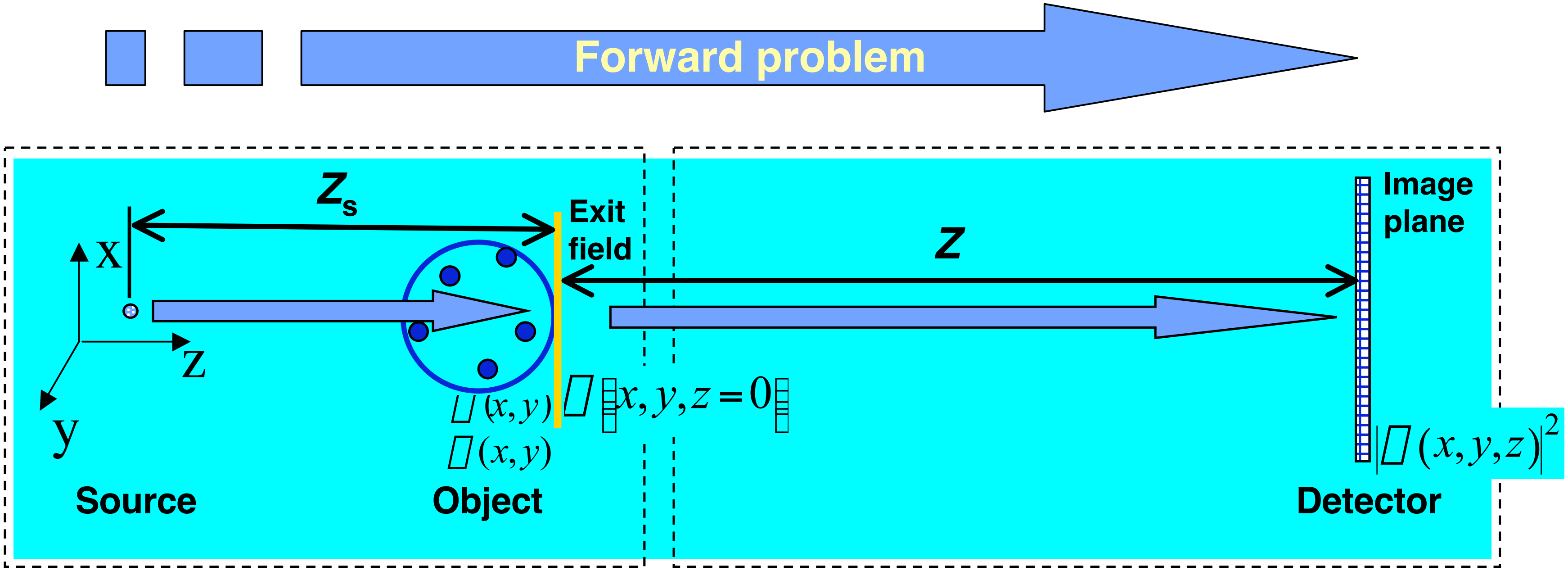
$$\square = \frac{2\square}{\square} \square\square \ell$$

$$\square = \frac{4\square}{\square} \square\square \ell$$

- HADES then computes the Fresnel integral.



Modeling phase effects with HADES



Exit wave

$$\psi(x,y,z=0) = \sqrt{e^{-\mu(x,y)}}\, e^{i\phi(x,y)}$$

The wave function on planes z > 0 is given by the Fresnel integral

$$\psi(x,y,z) = \frac{i}{\lambda z} e^{-ikz} \iint \psi(x',y',0)\, e^{\frac{i\pi}{\lambda z'}\left[(x-x')^2+(y-y')^2\right]} dx'dy'$$

where $z' = \frac{z}{1+z/z_s}$

Computing Fresnel Diffraction in HADES

- HADES computes the exit wave:

$$\psi(x,y,z=0)=\sqrt{e^{-\mu(x,y)}}\,e^{i\phi(x,y)}$$

- The Fresnel integral is needed:

$$\psi(x,y,z)=\frac{i}{\lambda z}e^{-ikz}\iint\psi(x',y',0)\,e^{\frac{i\pi}{\lambda z'}\left[(x-x')^2+(y-y')^2\right]}dx'dy'$$

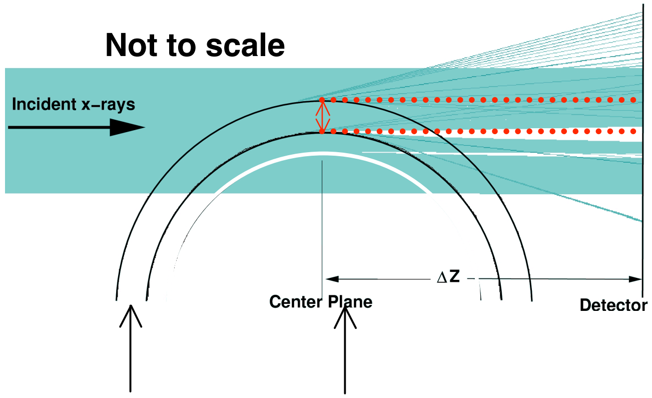
$$\text{where}\quad z'=\frac{z}{1+z/z_S}$$

- We use the convolution form of the Fresnel Integral:

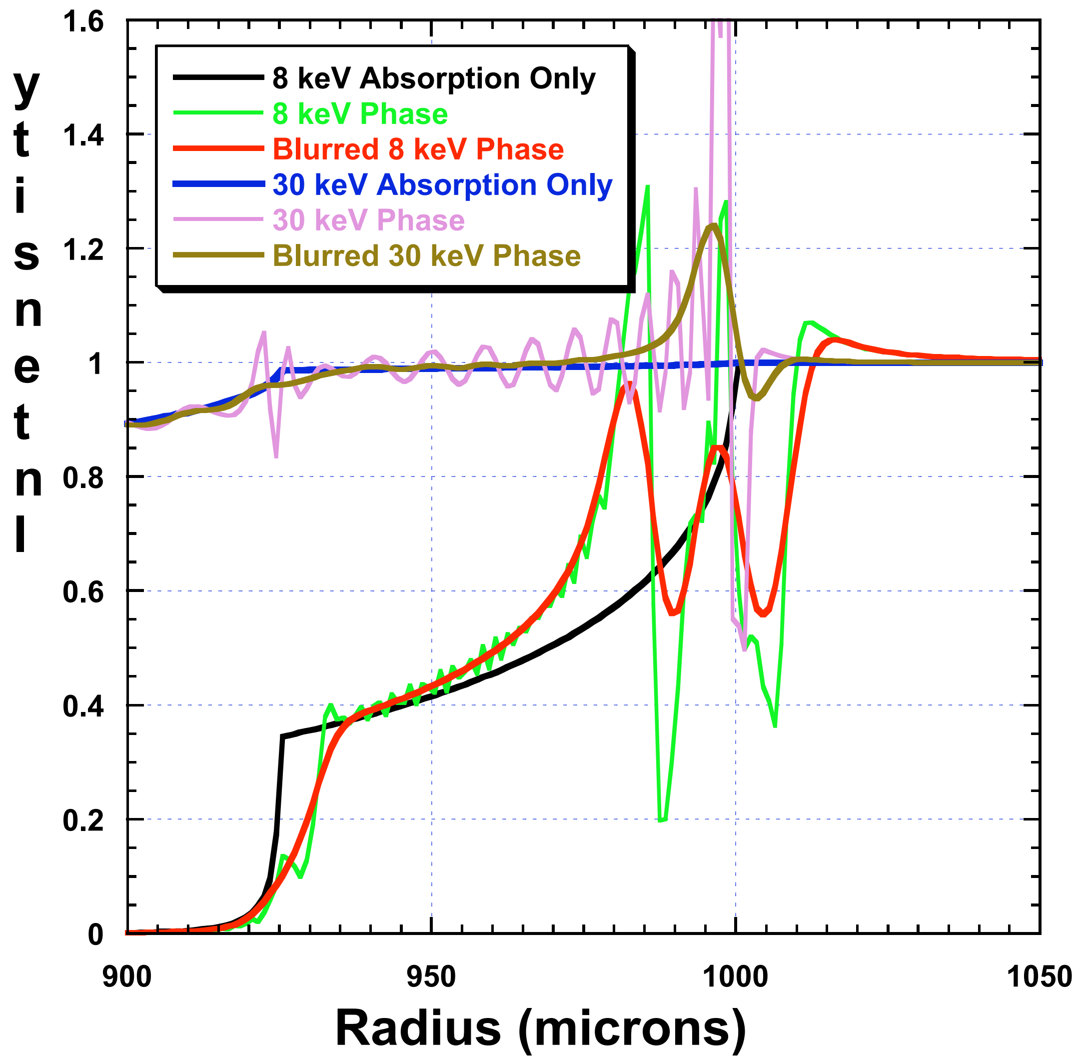
$$\psi(x,y,z)=e^{ikz}\,\mathcal{F}^{-1}\left\{e^{-i\pi\lambda z'\frac{ii^2+jj^2}{(N\Delta x)^2}}\,\mathcal{F}\{\psi(x',y',0)\}\right\}$$

- We use the FFTW library for the Fourier transforms

Application to Si_3N_4/Diamond System

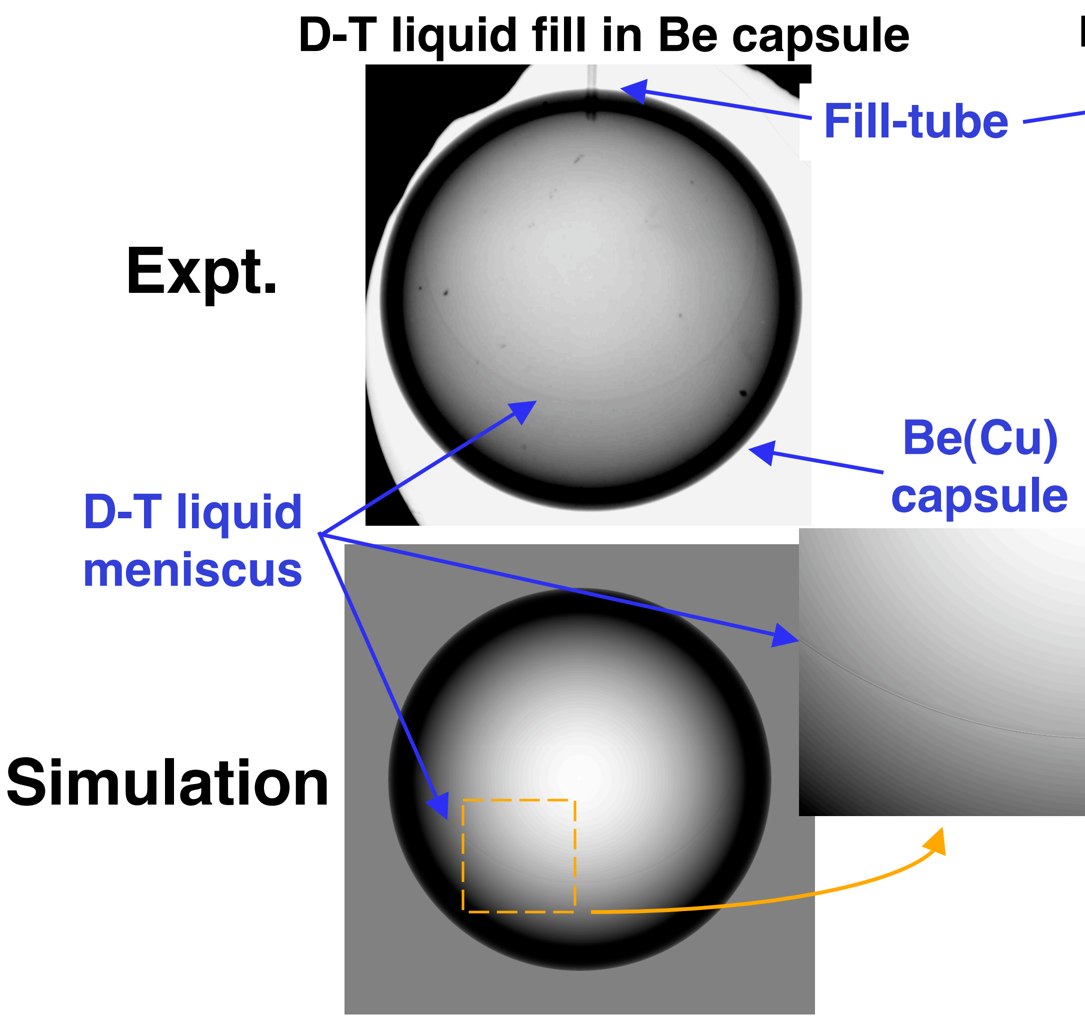


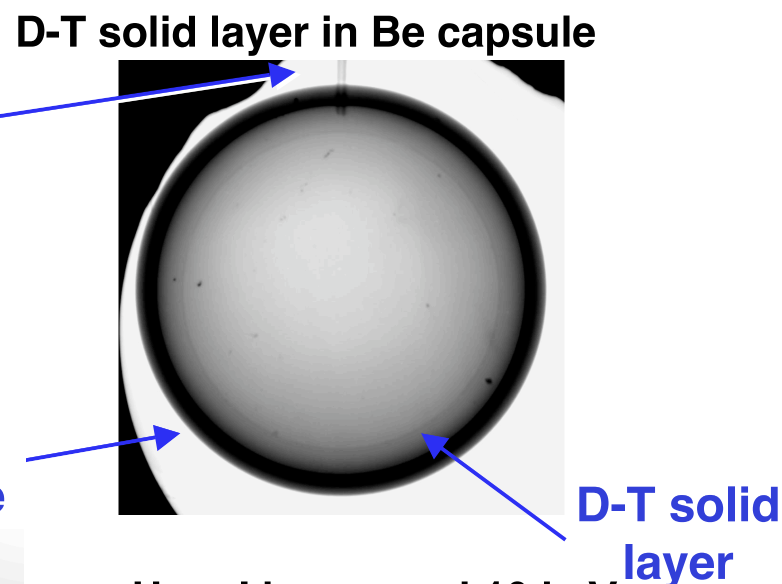
Diamond shell on Si_3N_4 mandrel



- These simulations used 1 micron pixels.
- Experimental resolution blurs out some of the diffractive effects.
- Here we used a Gaussian blur with = 3 microns.

Application to Be capsule + DT Ice/Liquid





- Here I have used 10 keV photons
- The source was polychromatic and there is strong spectral sensitivity because of detector and object K edges along the spectrum.
- More detailed spectral modeling will be done in the future.

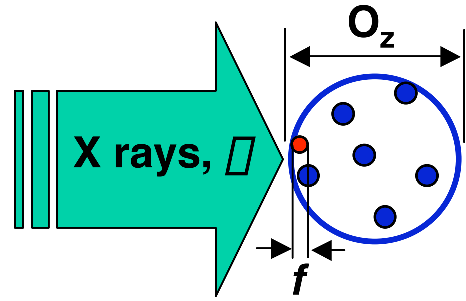
Diffraction limit within the object modeling

If O_z is the object size along z

f is the feature size and

λ is the wavelength

when $O_z > f^2/\lambda$ diffraction effects within the object become significant



In such a case, simple ray tracing is not adequate and *multislice* methods are needed.

Preliminary results indicate diffraction effects

not an issue for 60 keV

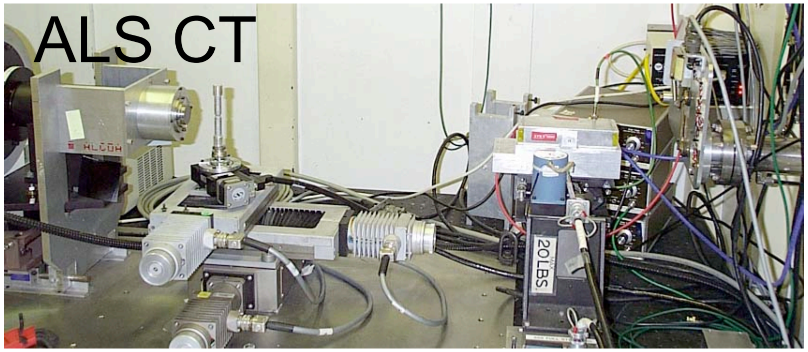
may be for 8 keV x-rays

We will be testing these issues experimentally.

X-ray imaging systems for validation

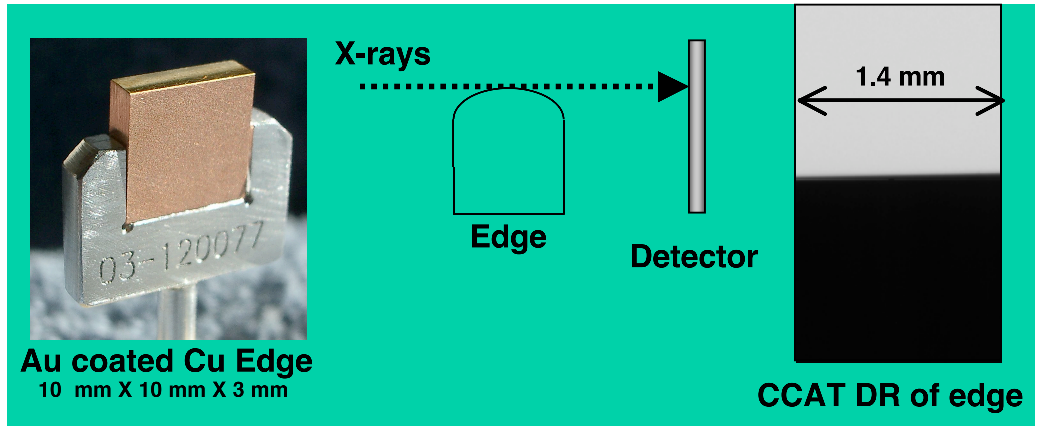
Multiple energy Micro Focus

"Single" energy synchrotron

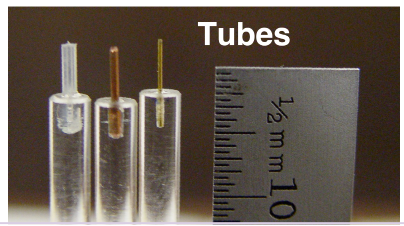


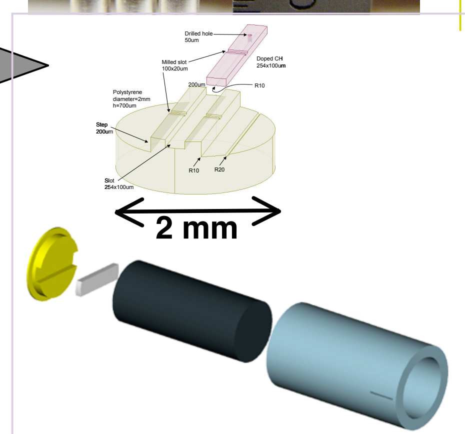
2D and 3D phantoms are useful for validation

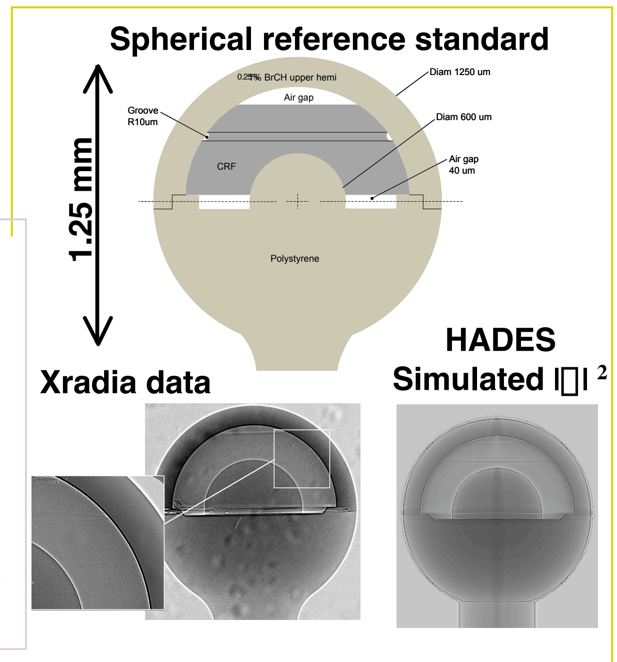
- Radiographic or 2D phantoms
  - Au coated Cu Edge
  - Ta edge
  - Plastic rod
  - Multiple material step wedge preliminary design completed



- Tomographic or 3D phantoms
  - Plastic rod
  - LDPE, Cu and Au tubes
  - Ethylene glycol solution in plastic tube
  - LX17 pellet
  - Cylindrical reference standard
  - Spherical reference standard







We are using available x-ray DR/CT systems

Conclusions

- The National Ignition Facility is driving R&D in fabrication and NDE of small, intricate targets for laser and ICF experiments.
- We are modeling the phase effects of low energy radiography of these targets for NDE applications.
- HADES is now modeling diffractive effects
  - We need to verify the code against semi-analytic cases
  - We need to validate HADES against experimental data
- We will be taking data for this validation in the next year.
- We are hoping to "correct" for phase effects so that standard CT can be used.